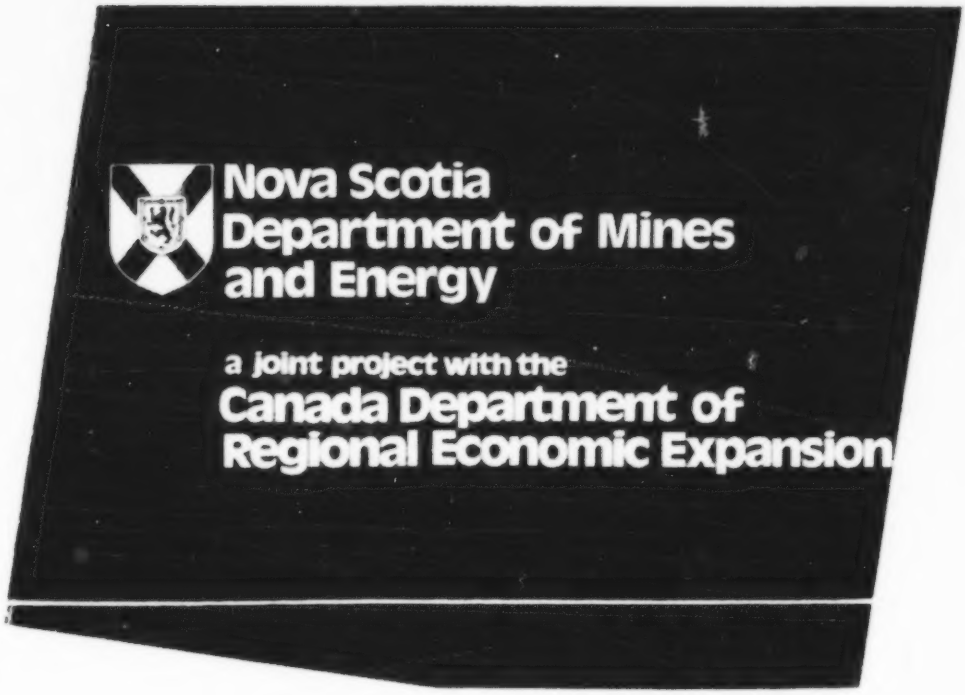
Minor and Trace Element Variatior In Wisconsinan Tills, Eastern Shore Region, Nova Scotia

by R.R. Stea and J.H. Fowler



PROVINCE OF NOVA SCOTIA

DEPARTMENT OF MINES & ENERGY

PAPER 79-4

MINOR AND TRACE ELEMENT VARIATIONS IN WISCONSINAN TILLS, EASTERN SHORE REGION, NOVA SCOTIA

by

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HALIFAX, NOVA SCOTIA

1979

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106-0 5762 /

TABLE OF CONTENTS

Page

Abstract 1
Introduction 1
  Mapping and sampling techniques 3
  Laboratory techniques 4
  Bedrock geology 5
  Previous work 5
Stratigraphic variations in sedimentological, lithological and
  geochemical properties of tills 7
  Hartlen Point section 7
  Terminal Beach section 10
  Wine Harbour Bay section 14
  Correlations and genetic interpretations of the till sheets 14
  Conclusions 16
Areal geochemical, sedimentological, and lithological variations
  in the mapped till groups 16
  Lawrencetown till 16
  Loose, sandy, till sheet 16
  "Bridgewater Conglomerate" 17
  Statistical analyses 17
    Means and standard deviations of the till groups 20
    Discriminant analysis 20
    Correlation matrix 22
Summary of main conclusions 25
Till units as prospecting tools: discussion 26
  Lawrencetown till 26
  Quartzite, slate, and granite tills 26
  Hartlen till 27
Acknowledgements 27
References 27

LIST OF TABLES

Table 1 - Mineralization environments of the Eastern Shore region 6
Table 2 - Summary statistics for Eastern Shore tills 21
Table 3 - Plot of discriminant scores for the till groups 23
Table 4 - Pearson correlation coefficients 24

LIST OF FIGURES

Figure 1 - General geology of the Eastern Shore region 2
Figure 2 - Contact of Lawrencetown till (red) with Hartlen till
  (grey) at Hartlen Point 8
Figure 3 - Till section at Hartlen Point 8
Figure 4 - Trace element variations in vertical section through two
  till sheets at Hartlen Point (modified after Podolak and
  Shilts, 1978) 9

Page

Figure 5 - Multiple till section, Terminal Beach, Halifax County 11
Figure 6 - Elemental variations in the clay fraction of till sheets exposed at Terminal Beach 12
Figure 7 - Iron oxide bands in gravel bed outcropping at Terminal Beach 13
Figure 8 - Folded lacustrine sediments at the core of a drumlin at wine Harbour Bay 13
Figure 9 - Correlations of till sheets exposed along the Eastern Shore 15
Figure 10 - Slate till; lithological facies of the loose sandy till sheet 18
Figure 11 - Granite till; lithological facies of the loose sandy till sheet 18
Figure 12 - Quartzite till; lithological facies of the loose sandy till sheet 19
Figure 13 - "Bridgewater Conglomerate" at Musquodoboit Harbour 19

LIST OF MAPS

Map Sheet 1 ..... in pocket
Map Sheet 2 ..... in pocket
Map Sheet 3 ..... in pocket

ABSTRACT

Tills in the Eastern Shore region of Nova Scotia were classified, sampled, and analyzed for a series of 15 elements including: Cu, Pb, Zn, Ni, Co, Fe, Mn, Mg, Ca, Hg, As, Mo, Ag, Cd, and U. The classification attempted to isolate till geochemical populations using genetic, sedimentological and lithological criteria. Discriminant analysis was used to test these classifications.

Tills in the region are of two basic types: the widespread, oligomictic, locally derived, sandy till sheet and the polymictic, red clay Lawrencetown till comprising the bulk of drumlins in the region and partly derived from sources north of the region. The sandy till sheet was subdivided, for statistical analyses, into lithological till types or facies, namely quartzite, slate and granite tills which reflect closely their parent Cambro-Ordovician Megurna Group and Devonian granitic bedrock sources. Lawrencetown till was subdivided into two facies: the red clay facies and the sandy facies. These represent minimum and maximum incorporation of locally derived bedrock in the till matrix.

The clay size ($<2\mu$) fraction (centrifuged) was used in the analyses. Most of the samples were taken from the weathered zone (<2m) of surface outcropping tills. In this zone leaching of labile minerals releases metal cations which are scavenged by the clay fraction.

Significant differences in trace element geochemistry were found between lithological till types, and between Lawrencetown till and quartzite till, the two main sampling ~its of the region. Quartzite till mean Cu, Ni, Co, Fe, Pb, and Cd values were distinctly higher than Lawrencetown till values. The sandy facies of Lawrencetown till was found to exhibit intermediate mean Cu, Ni, Co, Fe, and As values between the foreign red clay facies and the local quartzite till.

It is suggested that the two main sampling units, Lawrencetown till and quartzite till, are geochemically distinct due to their compositional and sedimentological differences, and that any samples of derived lake sediment, stream sediment or soils from terrain underlain by either till may show similar basic chemical differences.

INTRODUCTION

A survey of the till in the Eastern Shore region of Nova Scotia (Fig. 1) was undertaken with the following objectives:

(1) to map the major till types of the Eastern Shore region and classify them using lithological, textural, and genetic criteria.

(2) to differentiate the till types using chemical parameters.

(3) to define the causes of variability of minor and trace concentrations in this sediment:

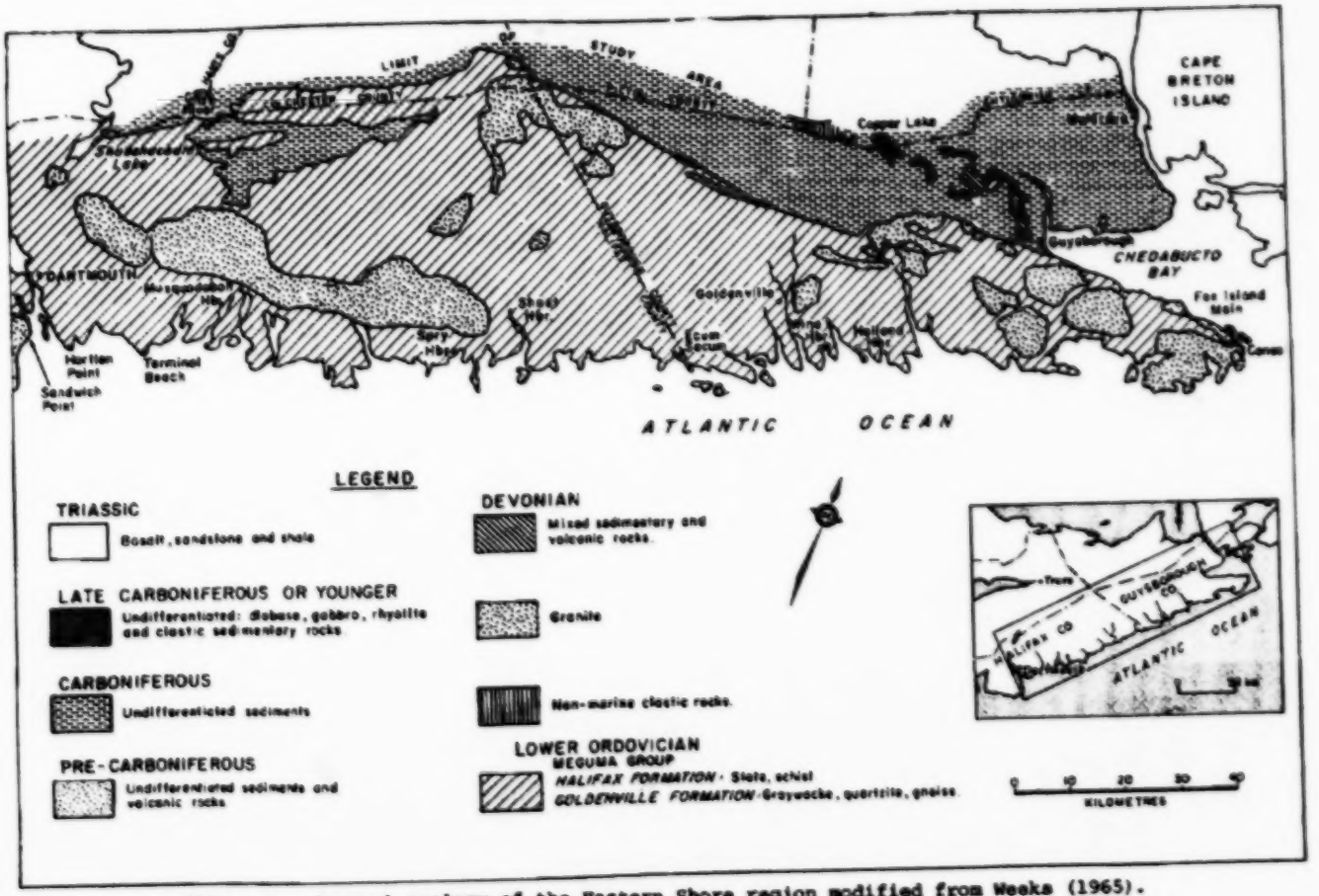


Figure 1. General geology of the Eastern Shore region modified from Weeks (1965).

(4) to compare the results with a regional lake sediment survey undertaken in the same area.

From an exploration viewpoint, classification and mapping of the tills, in addition to normal chemical determination, is desirable. Till lithology has long been known to reflect the character of both the underlying bedrock and the sediments overridden by the glacier (see for example, Dreimanis, 1976). Holman (in Boyle, et al., 1963) found that mean values of Cu, Pb, and Zn in stream silts varied according to underlying rock types in the study region. It was assumed that lithologically classified till would show similar compositional differences, and that any samples of derived sediment, or soil, would also reflect these chemical variations. Shilts (1975) pointed out that sampling error is considered significant if different genetic types of till are mixed and considered to be one population for sampling and analytjcal purposes. The mapping and classification, by reducing the sampling error of mixing these populations, enhances the interpretation of anomalous areas. The authors used statistical analyses to determine the background values and variances of elements in the till types. Discriminant analysis (Klovan and Billings, 1967) was also used to define the till populations statistically.

Previous studies by Forslev (1957) and May and Dreimanis (1973) used geochemical parameters to differentiate between tills deposited by different glacial lobes. This study attempted to classify and discriminate among local tills by using chemical parameters.

Mapping and Sampling Techniques

The project area includes all of Guysborough County arid the central and eastern sections of Halifax County, a total area of 10,200 km^2. Logging roads provided access to the interior of these counties, and highway 7 skirts many coastal exposures. Sampling density is variable, the average being approximately one sample per 25 krn^2. Samples were obtained from fresh exposures in road and stream cuts, pits and sea cliffs., at an average depth of 2 m. Thick sections with one or more till units exposed were systematically sampled at 0.5 to 1.0 m intervals.

Till units were described, classified and mapped using field data, information from soil survey reports (MacDougall, et al., 1963; Hilchey, et al., 1964) and surficial maps published by the Nova Scotia Research Foundation (MacNeill, 1956). Extensive air photo interpretation was used, especially in the mapping of drumlin distribution.

The clay size fraction ($<2\mu$) of the till matrix was analyzed. The reasons for selecting the clay size fraction ($<2\mu$) for chemical analyses were first discussed by Ridler and Shilts (1974) and Shilts (1975) and are as follows:

(1) Most samples (average sampling depth < 2 m) have been stripped of labile components (sulphide and carbonate mineral grains) by weathering. The clay fraction fixes a proportion of the lost cations (Shilts, 1975).

(2) The clay fraction contains most of the metal Leached from weathered samples. The sand and silt sized matrix was not used because it varies in percentage from one till type to another and the amount of metal poor sand and silt obtained by conventional sieving techniques can cause trace element concentrations to vary to such an extent that they are not easily related to geological factors.

(3) The clay fraction demonstrates relatively little depth variation when compared to sieved fractions containing sand and silt sized material.

(4) The clay fraction is thought to contribute substantially to lake sediments, making correlation of results with the lake sediment survey possible (Podolak and Shilts, 1978).

Laboratory Techniques

All samples were prepared and assayed by the Laboratory for the Investigation of Minerals, Nova Scotia Technical College, Halifax, Nova Scotia. Analyses were done on the clay size (< 2μ) fraction of the sample. Most samples were assayed for fifteen elements, namely Cu, Pb, Zn, Ni, Mo, Fe, Mn, Cd, Ag, Hg, Co, U, As, Ca and Mg.

Preparation of samples for assay followed the method developed by the Drift Prospecting Laboratory, Geological Survey of Canada (Higgins, et al.) with a slight modification. A porcelain ball mill with one silica pebble was used to mix the sample and the dispersant (metaphosphate solution) .The ball mill was rotated for a period of fifteen minutes for each sample. Samples containing a low volume of fine (<2μ) material were reprocessed to obtain as much fine material as possible for the analyses. These samples were analyzed for as many elements as possible determined by the amount of fine material that could be extracted.

Analyses for Cu, Pb, Zn, Hg, Ni, Fe, Ma, Cd, Ag, Co, As and Mn followed the method of Hornbrook and Garrett (1976). Ca and Mg were assayed using a method devised by the Laboratory for the Investigation of Minerals, Nova Scotia Technical College. U was assayed following the method of Smith and Lynch (1969).

A Jarrel Ash Model 810 A.A. unit was used to determine the level of concentration of Cu, Pb, Zn, Ni, Mo, Fe, Mn, Cd, Ag, Co, Ca and Mg in the samples. A Fisher Electrophotometer II unit was used to detect As. U was detected with a Model III Fluormeter manufactured by G. K. Turner Associates. A Perkin-Elmer Coleman 50 Hg Analyses System was used to detect Hg.

Bedrock Geology

The study area is underlain by sedimentary, igneous and metamorphic rocks (Fig. 1). The Cambro-Ordovician Meguma Group is composed of a sandy flysch (Goldenville Formation) overlain by a shaly flysch (Halifax Formation) (Schenk, 1971). In the study area the group is regionally metamorphosed up to the lower amphibolite facies (Taylor and Schiller, 1966) and deformed in a series of upright northeasterly trending, subhorizontal folds associated with axial plane cleavage and gold occurrences (Faribault, *in* Malcolm, 1929; Keppie, 1976). Granitic rocks of Silurian-Lower Carboniferous (Fairbairn, et al., 1960) age intruded the Meguma Group.

Volcanic rocks, which may be pre-Mississippian, are located in a fault disrupted zone north of the Guysborough River. These consist of maroon amygdaloidal rhyolites, dacites and andesites (Schiller, 1961). Lower Mississippian Horton Group strata cover a broad area in Guysborough County and consist of shales, sandstones and conglomerates that are complexly folded and faulted (Schiller, 1961).

The Windsor Group (Middle to Upper Viséan), a sequence of evaporites (limestone, gypsum, salt) and terrestrial red beds (shale, sandstone, conglomerate), overlies the Horton Group conformably. These rocks underlie most of the Musquodoboit Basin in the study area. Carboniferous strata underlie approximately 35% of the study area. Diabase dykes, sills and gabbro plugs intruded Horton strata in Guysborough County. Triassic red shales and sandstones outcrop in the bed of the Salmon River, and at a few localities along Chedabucto Bay. See Table 1 for a summary of mineralization environments of the Eastern Shore region.

Previous Work

Grant (1963) investigated the tills in the area and elucidated the occurrence of major till types. He found that the region is characterized by a widespread, loose, oligomictic, sandy till sheet developed on the resistant upland mass of Cambro-Ordovician quartzites and slates (Meguma Group), and Devonian granitic rocks. Grant (1963) recognized that these tills are related closely to underlying bedrock, demonstrating rapid facies transitions over adjacent rock types. He also noted an anomalous, red, polymictic, relatively clay-rich till occurring in drumlins on Meguma terrane of the upland region. He related the red drumlin till to a similar parent till covering the Carboniferous lowlands to the north. He believed that drumlin till was a product of dilution of the parent till with local rock or ground moraine (Grant, *in* Prest, et al., 1972, p. 7). Underlying this till, in certain exposures, is a grey, compact clay till with clasts of predominantly local origin. He also recognized an iron-cemented diamict known as the "Bridgewater Conglomerate" in the region, which he considered to be a remnant of pre-Wisconsinan outwash deposits (Grant, *in* Prest, et al., 1972, p. 120).

TABLE 1. Mineralization environments of the Eastern Shore region.

LOCATION	HOST ROCK/AGE	TYPE OF MINERALIZATION	ELEMENTAL ASSOCIATION*
Goldenville 11E1	Interbedded sequence of slates & quartzites Goldenville Formation Early Ordovician	Saddle reef: quartz veins	As, Au (Fe, Cu, Zn)
Ecum Secum 11D16	Slate bands Goldenville Formation Early Ordovician	Saddle reef: quartz veins	As, Au (Fe, Pb, Cu, Zn)
Dunbrack (Musq. Hbr.) 11D14	Granite Devonian	Fissure veins	Pb, Ag, Cu (Sb, Zn)
Gays River 11E3	Limestone Windsor Group Early Carboniferous	Mississippi Valley	Pb, Zn (Ag, Cd, Mn, Sb, Co, Fe, F)
Copper Lake 11F5	Slate and quartzite Horton Group Early Carboniferous	Fault controlled veins	Cu, Fe**
Fox Island Main 11F6	Quartzite Goldenville Formation Early Ordovician	Stock works	W, Cu (As, Fe)

*Major elements are shown with associated elements in brackets.
**Fe at Copper Lake occurs as a carbonate.

Stratigraphic relations between the red clay till and the loose sandy tills are seemingly contradictory. Grant (1963, p. 122) stated: "The best way to describe the relationships without risking gross misinterpretation, is to say the drumlins swim in; rather than on or under, the till sheet" (loose, sandy till sheet). The polymictic, red clay till which comprises the bulk of drumlin volume in the Eastern Shore region, has been named Lawrencetown till by Grant (1975).

STRATIGRAPHIC VARIATIONS IN SEDIMENTOLOGICAI LITHOLOGICAL, AND GEOCHEMICAL PROPERTIES OF TILLS

Till sheets lying in stratigraphic succession were compared on the basis of composition and texture. Two deep till exposures were systematically sampled in order to determine the amount of variability between the till sheets. Superposed tills may be evidence of deposition of till during each of several glacial advances, or facies (i.e. basal, ablation tills) of one glacial event, or a combination of both. Transportation distances and directions may differ between till sheets. Variability of trace element concentrations caused by compositional differences may be significant between till sheets (Shilts, 1976).

In addition to primary sedimentological differences between till sheets, weathering processes may affect the concentrations of some metals in the clay fraction of near surface samples. Variability due to weathering will ultimately depend on the depth of oxidation in a surface outcropping till member (Shilts, 1975, 1976). Sections at Hartlen Point and Terminal Beach were chosen to illustrate the variability of trace elements with depth in areas of thick till exposure. Hartlen Point is considered as a reference section in this study.

Hartlen Point Section

Two tills (Fig. 2) are exposed in a sea cliff at Hartlen Point (Fig. 1) southeast of Dartmouth. The lower till is grey, compact, with a silty matrix that is homogeneous and structureless (Nielsen, 1976, p. 39). This till has been informally designated as Hartlen till by the authors. It contains approximately 90% quartzite clasts and about 5% foreign clasts. Hartlen till is extremely compact, forming steeper slopes than the overlying Lawrencetown till. The upper Lawrencetown till (Fig. 3) is enriched in foreign pebbles (15%) and has a red clay matrix.

The geochemical profile of this section (Fig. 4) is adapted from Podolak and Shilts (1978) and illustrates the distinct chemical differences in the heavy mineral and clay fractions of these two tills. The upper Lawrencetown till, a basal melt out till, according to Nielsen (1976), is enriched in sulphides, particularly zinc (1070 ppm) in the heavy mineral fraction. This suggests a different provenance than the Hartlen till, which is enriched in Ni, Co, Fe and U (Podolak and Shilts, 1978).

Figure 2. Contact of Lawrencetown till (red) with Hartlen till (grey) at Hartlen Point.

Figure 3. Till section at Hartlen Point. Note boulder pavement above the Lawrencetown till - Hartlen till contact.

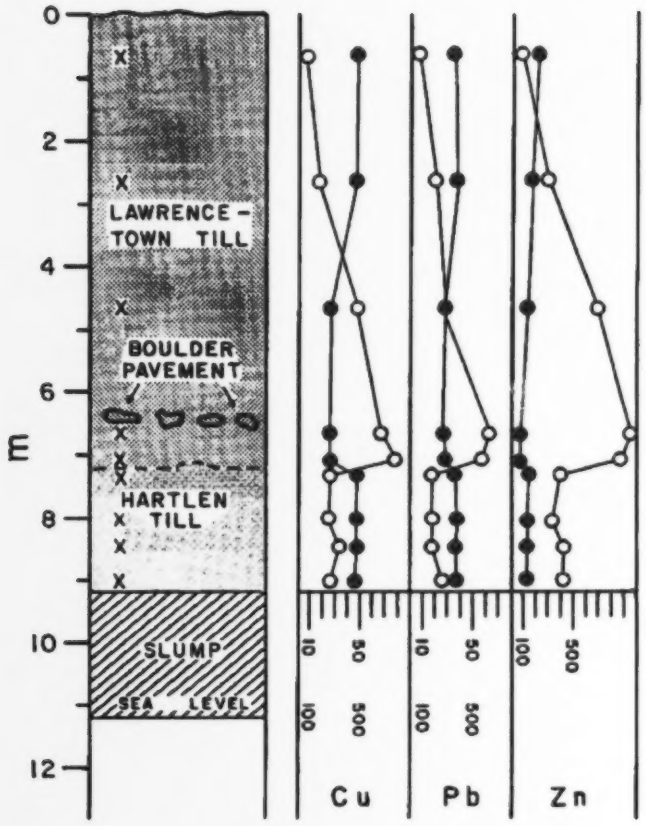


Figure 4. Trace element variations in vertical section through two till sheets at Hartlen Point (modified after Podolak and Shilts, 1978).

Paradoxically, neither till is distinguishable on the basis of its translucent heavy mineral assemblage (Nielson, 1976, p. 113).

The effects of weathering are evident in the upper 3 m of the till section. The transition from unoxidized to oxidized till is revealed by the disappearance of labile sand-sized heavy minerals Cu and Zn (Podolak and Shilts, 1978). There is a subsequent increase of trace element concentrations in the clay fraction due to scavenging of the released cations by clay minerals and iron-manganese oxides. Oxidation in the weathering zone is evidenced visually by manganese oxide staining along fissility planes.

Terminal Beach Section

This section occurs along the shoreline 20 km east of Dartmouth (Fig. 1) .The sequence consists of a lower, grey compact till overlain by fluvial sediments and an upper unit of grey compact till, tentatively correlated with Hartlen till, capped by 2 m of Lawrencetown till (Fig. 5). The lower and upper grey tills are similar in texture and are characterized by a silty matrix, pebble-sized, angular quartzite clasts, and some sand inclusions. The lower grey till has a very low foreign clast component (<3%). The upper grey till, in contrast, contains 5-7% of the far-travelled clasts.

The upper Lawrencetown till is fissile and has a silty sand matrix. It contains approximately 13% foreign clasts. Manganese oxide staining is evident along fissility planes.

The geochemical profile of this section (Fig. 6) demonstrates elemental variations among till sheets. Weathering changes, may be superimposed on compositional variations in the Lawrencetown till. The increase of manganese and the low calcium values in the samples of Lawrencetown till indicate active weathering processes occurring within this till.

Lead values are uniformly higher in the upper Hartlen till, averaging 45 ppm. Extremely low values of lead and copper occur in the lower grey till bed (Pb 3 ppm, Cu 10 ppm). Manganese and calcium values in the Lawrencetown till differ substantially from the lower tills (Mn 1080 ppm, Ca 940 ppm).

The fluvial unit shows the effects of precipitation of iron oxide on trace element geochemistry. The higher values of Cu, Pb, Zn (Cu 81.4 ppm, Pb 38 ppm, Zn 200 ppm) correspond to an increase of Fe (5.58%) precipitated as iron oxide in the oxidizing environment of this aquifer (Fig. 7).

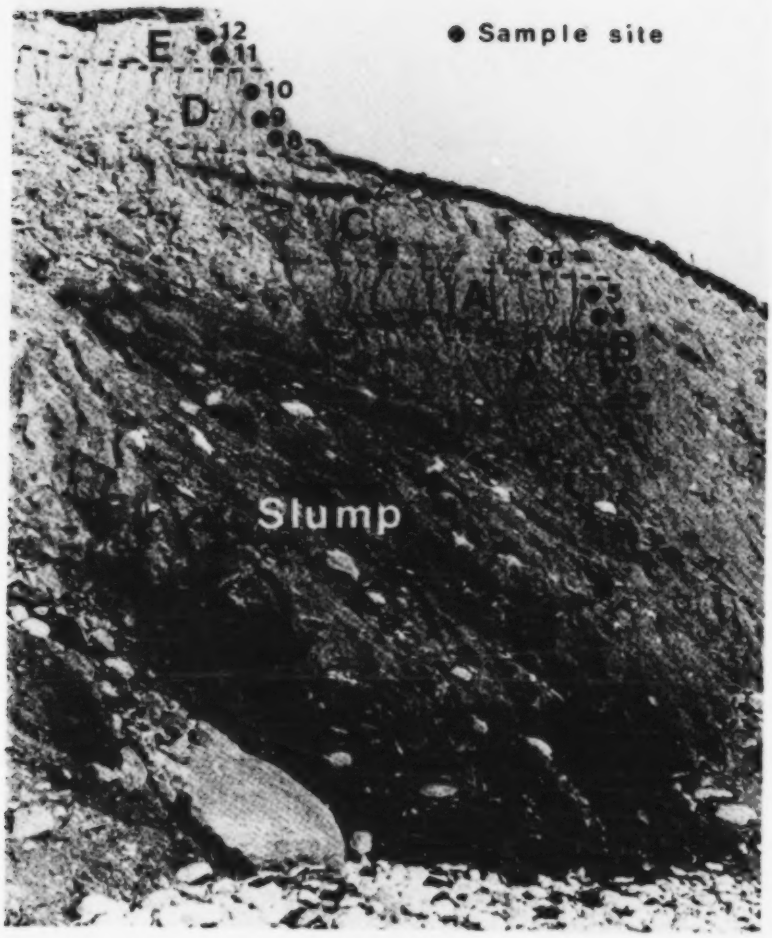
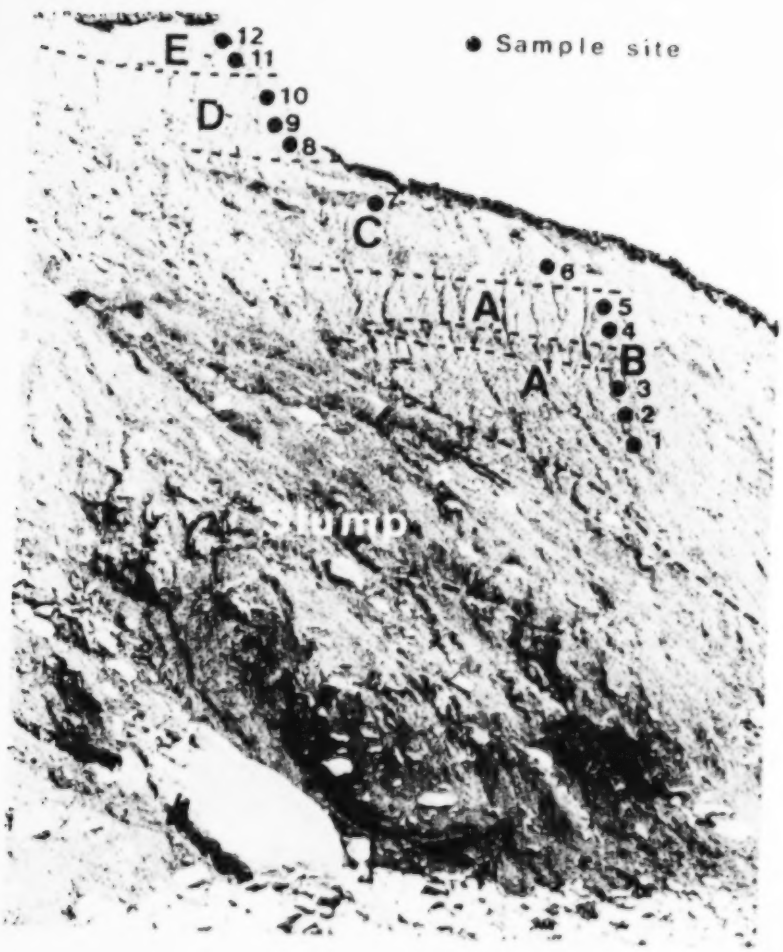


Figure 5. Multiple till section, Terminal Beach, Halifax County.
A. Grey compact silt till.
B. Sand lens.
C. Glaciofluvial sand, silt, and gravel.
D. Hartlen till.
E. Lawrencetown till.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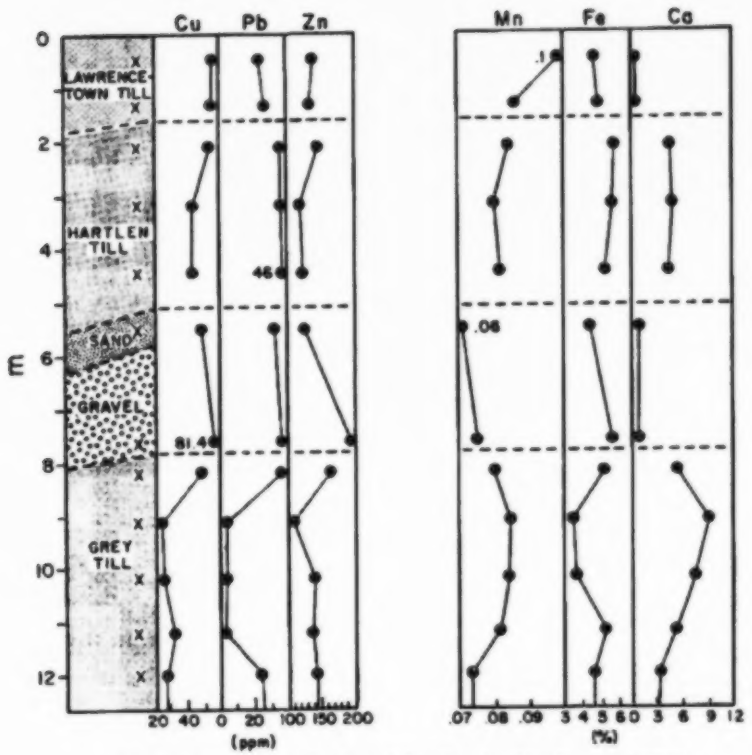


Figure 6. Elemental variations in the clay fraction of till sheets exposed at Terminal Beach.

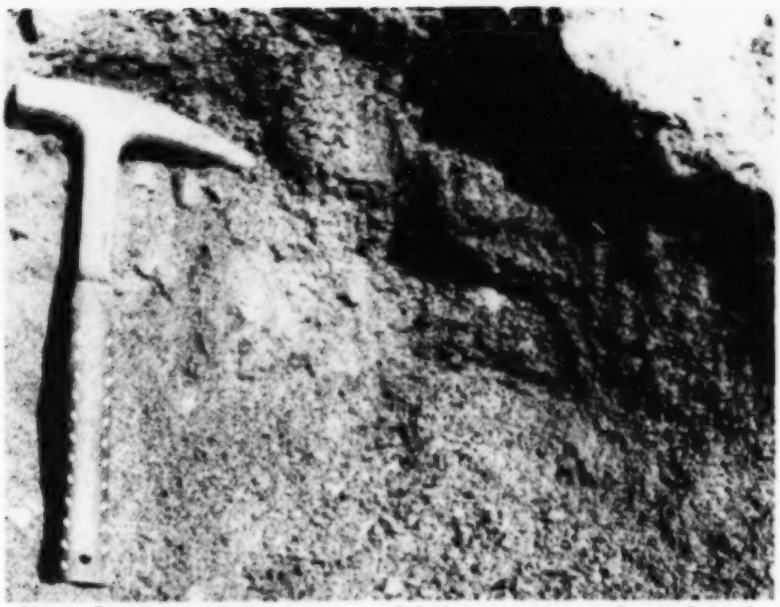


Figure 7. Iron oxide bands in gravel bed outcropping at Terminal Beach.

Figure 8. Folded lacustrine sediments at the core of a drumlin at Wine Harbour Bay.

Wine Harbour Bay Section

Two eroded drumlins, up to 20 m high, are exposed at wine Harbour Bay, Guysborough County (Fig. 1) in a sea cliff cut transverse to their north-south trending long axes. High tide waters wash the base of the drumlin section keeping the face relatively clean of slump. Exposed on the boulder beach at the base of the drumlin section is a bluish-grey clay till. This till is compact and is composed predominantly of pebble-sized clasts which are 90% quartzite (Goldenville Formation), 5% red sandstone (Horton Group?), and 5% granites (Devonian). This till thickens on the southeast side of the drumlin section. Above the bluish-grey till, on the southeast side of the drumlin section is a lens-like sheet of cobbly quartzite till, greenish grey in colour. The tills are separated by sharp boundaries. The quartzite till is apparently overlain by bouldary red silty till, but the red till and quartzite till are interlayered with the red till comprising the bulk of the drumlin material. There seems to be an alignment of boulders in this till resembling stratification.

Underlying the grey till at the core of the drumlin section is a folded unit of laminated silt and fine sand of probable glacio-lacustrine origin. The laminated unit has been recumbently folded (Fig. 8). Pressure from an overriding glacier is suggested as the cause of the folding of these sediments.

Correlations and Genetic Interpretations of the Till Sheets

Figure 9 represents a correlation of till sheets along the Eastern Shore. The red silty till at Wine Harbour is correlated with Lawrencetown till at Hartlen Point and Terminal Beach on the basis of its colour and high foreign clast component. The lowermost grey till at Terminal Beach was not correlated with Hartlen till as the possibility exists that it may represent an earlier glacial event. Hartlen till was originally described by Grant (1963, p. 136) as a compact till deposited during a glacial event separate from that which deposited the upper Lawrencetown till within the late Wisconsinan substage. Grant (1976) later revised his earlier stratigraphy, correlating the Lawrencetown till with the lowermost red till at Salmon River, Digby County, inferred by paleontological evidence to be early Wisconsinan in age. Nielsen (1976, p. 186) , maintained that Grant's early stratigraphy was "unjustifiably complex". He hypothesized that the Hartlen till was deposited as a lodgement till in "early" late Wisconsinan time, then partially eroded and the Lawrencetown till was deposited, without a major interstadial period intervening.

Fabric data show each till to have been deposited by glaciers with differing directions of flow (Nielsen, 1976, p. 67). The Lawrencetown till is believed to have been deposited by a southerly-southeasterly flowing ice sheet (Grant, *in* Prest, et al., 1972, p. 8). The sense of movement of the ice sheet that produced the Hartlen till is uncertain. Fabric measurements and clast lithology of a correlative till at Sandwich Point, Halifax County, indicated an onshore movement (Stea, unpub.

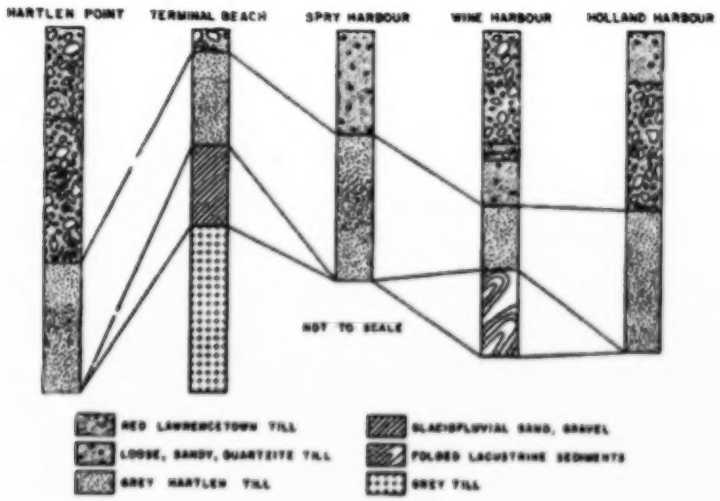


Figure 9. Correlations of till sheets exposed along the Eastern Shore.

The loose, sandy till sheet surrounding drumlins and mantling the Lawrencetown till in some drumlins, is difficult to place into lodgement or ablation origins (Podolak and Shilts, 1978) and to time of formation. It may be:

(1) a basal till deposited during a separate glacial advance, later than the Lawrencetown till (Grant, 1963, p. 172). Grant (1963) also considered that it could have been deposited before and during the advance that produced the Lawrencetown till.

(2) an ablation phase of the ice advance which produced the Lawrencetown till (Nielsen, 1976).

The two grey tills at Terminal Beach may represent a series of depositional episodes separated by a minor recessional period. They may also represent a single till bed stacked by glacial thrusting (Shilts, pers. comm.).

Conclusions

Differences in trace element content due to compositional and textural changes between till sheets has been noted for major till sheets along the Atlantic Coast. There are also variations between weathered and unweathered samples of till in a surface outcropping till sheet. It can be assumed that since the compact Lawrencetown till, relatively impermeable to water, is weathered to depths of 2.5 m (Fig. 4) it would follow that the loose sandy tills would show a greater degree and depth of weathering. The oxidizing conditions above the water table may extend to bedrock in some areas. The regional water table depth in upland areas, covered by a veneer of porous sandy till, is 4-5 m (H. Cross, N. S. Dept. of Environment, pers. comm.).

AREAL GEOCHEMICAL, SEDIMENTOLOGICAL AND LITHOLOGICAL VARIATIONS IN THE MAPPED TILL GROUPS

Lawrencetown Till

Lawrencetown till in drumlins varies in composition and texture, between drumlin fields, down ice from their parent till sheet, and within individual drumlins (Stea and Fowler, 1978). The drumlins become progressively enriched in local pebbles down ice from their source area (Grant, *in* Prest, et al., 1972, p. 7). Drumlin till also becomes enriched in sand and local clasts as the periphery of drumlin fields and the flanks of some individual drumlins are approached. This phenomenon may be due to the incorporation and subsequent deposition of local debris at the base of the glacier (quartzite, slate and granite bedrock) with foreign drumlin material carried englacially. The process of deposition of the Lawrencetown till is described by Nielsen (1976) as basal melting. Far travelled clasts in Lawrencetown till are similar in lithology to rocks outcropping in parts of the Antigonish and Cobequid Highlands, and the North Mountain.

The red clay, part of the matrix of the Lawrencetown till, is strikingly anomalous in drumlins on quartzite terrane, and is thought to have been derived wholly or in part from one or more of the following sources:

(1) Carboniferous or Triassic red beds (shales) (Cameron, 1961);

(2) pre-existing Wisconsinan estuarine muds (Grant, 1963);

(3) Cretaceous clays (Stea and Fowler, 1978).

Loose, Sandy, Till Sheet

The sandy tills, developed over the resistant upland areas, characteristically contain more than 90% local clasts. The tills are mixed down ice from bedrock contacts and form hybrids. Sandy tills usually contain foreign clasts in the order of 1-5%, however, there are

sandy tills contain inclusions of red clay and high percentages of foreign pebbles. It may be considered that there is a continuum of tills with properties derived from two "pure" end members, the oligomictic (eg. quartzite) sandy till and the polymictic Lawrencetown till.

Quartzite bedrock (Goldenville Formation) underlies approximately 60% of the study area. It is lithologically homogeneous throughout the region (McBride, 1978). Quartzite derived sandy till (quartzite till) is the most ubiquitous sampling unit on the upland areas of the region.

"Bridgewater Conglomerate"

The "Bridgewater Conglomerate" is a diamict of glacial origin (MacNeill, *in* Prest, et al., 1972). The "conglomerate" is composed largely of angular fragments of Meguma Group metasediments and granitic boulders in an iron oxide cemented matrix. It occurs frequently, in the study area, near granite (Devonian Batholith) and slate contact zones. The limonitic cement characteristic of the "conglomerate" may have formed as a result of the circulation of oxidizing groundwater reacting with the highly pyritiferous slates of the Halifax Formation. Stea (1978) suggested that some of the deposits in the study area are genetically related to ice contact stratified drift. He also noted that in some areas (i.e. Fishermans Harbour, Guysborough County) the "conglomerate" was only partially cemented presumably due to the admixture of unreactive quartzite fragments to the deposit.

Statistical Analyses

Statistical analyses were performed on the following groups of tills:

(1) Lawrencetown Till - includes the parent till sheet developed over Carboniferous bedrock and the drumlin till over the Meguma Group. The drumlin till is divided into two facies, the red clay and the sandy facies representing minimum and maximum incorporation of local rock into the till matrix.

(2) Slate, Granite and Quartzite Tills (Figs. 10, 11, 12) - are lithological facies of the loose, sandy till sheet containing >90% clasts of local derivation.

(3) Hartlen Till - includes samples from several basal units along the Eastern Shore believed to be correlative.

(4) "Bridgewater Conglomerate" - is an iron-cemented diamict of glacial origin (MacNeill, *in* Prest, et al., 1972; Stea, 1978) (Fig. 13).

Figure 10. Slate till: lithological facies of the loose sandy till sheet.

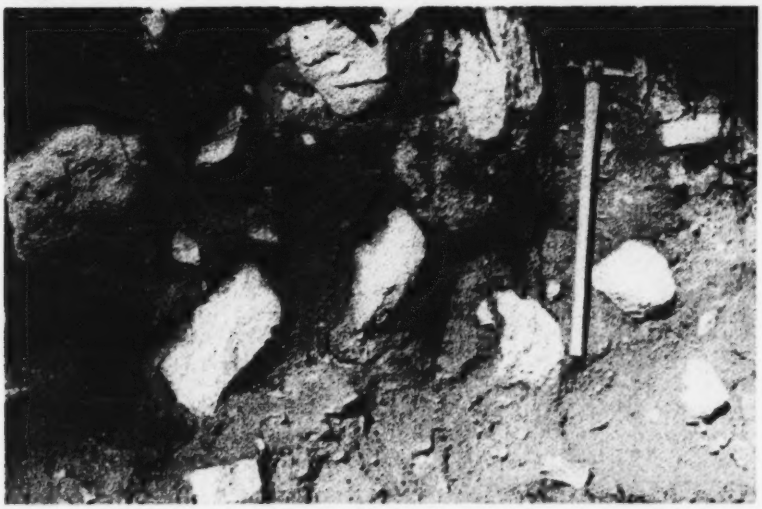


Figure 11. Granite till: lithological facies of the loose sandy till sheet. Note depth of weathering, i.e. red coloration.

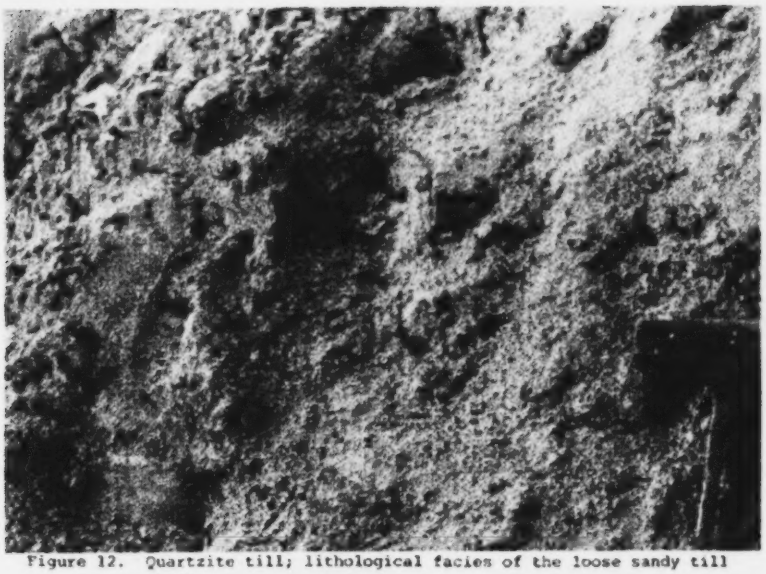


Figure 12. Quartzite till; lithological facies of the loose sandy till sheet.

Figure 13. "Bridgewater Conglomerate" at Musquodoboit Harbour. A = granite clast, B = slate clast, C = quartz (vein).

Means and Standard Deviations of the Till Groups

Table 2 gives a summary of the means and standard deviations of the groups considered. The clay facies of the Lawrencetown till, which contains considerable amounts of detritus from north of the Meguma terrane, shows substantially lower average Cu and Pb values (58.3 and 36.3 ppm) than the oligomictic, Meguma derived, till sheet (over 100 ppm Cu and Pb for slate and quartzite tills).

The variances of most of the elements in the Lawrencetown till are lower than in the sandy tills. The sandy facies of the Lawrencetown till has an intermediate position in mean As, Cu, Fe, Mn, Cd and Co values between the red clay facies and the predominant, locally derived quartzite till. This may be a reflection of its dual provenance, a mixture of local and distant material.

The iron-cemented "Bridgewater Conglomerate" is the most distinctly different till group geochemically. Mean values of Pb and Zn are elevated in the six samples taken (Pb = 305, Zn = 261).

Compositional differences occur between the lithological facies of the loose, sandy till sheet. Mean values for granite, slate and quartzite tills are significantly different for most of the analyzed elements, primarily Cu, Pb, Ni and Cd.

Discriminant Analysis

Comparing one or two elements at a time for these tills can be a long and unrewarding process. Discriminant analysis (Klovan and Billings, 1967) considers all elements simultaneously. It answers these questions pertinent to our study:

(1) Is the Lawrencetown till distinct statistically, considering all elements, from oligomictic, sandy tills?

(2) Can the lithological facies of the sandy till sheet be differentiated on the basis of the chemistry of the clay fraction?

(3) What elements are most important in the discrimination?

(4) How are the values for these elements distributed, in the different till groups?

The final result of this analysis is a discriminant score "D" which characterizes a sample chemically. This score is a function of the important elements that show significant differences between the till groups.

It was found that six elements contributed most in the discrimination of the tills. The discriminant function that best describes these tills was found to be:

TABLE 2. Summary statistics for Eastern Shore tills.

Element	Hartlen Till (n = 33.0)		Lawrencetown Till (red clay facies) (n = 155)		Lawrencetown Till (sandy facies) (n = 64)		Quartzite Till (n = 122)		Slate Till (n = 22)		Bridgewater Conglomerate (n = 5)		Granite Till (n = 14)	
	m	σ	m	σ	m	σ	m	σ	m	σ	m	σ	m	σ
Ag	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	na	na	na	na
Cd	0.0	0.0	0.3	0.2	0.8	0.7	0.9	1.0	0.6	0.4	na	na	na	na
Cu	96.0	48.1	58.8	27.0	65.5	18.8	134.8	83.9	109.4	76.5	130.4	22.8	58.7	40.1
Ni	53.5	21.3	46.9	8.7	47.5	9.6	60.7	38.3	39.3	34.4	35.8	20.5	30.0	14.8
Pb	44.1	35.6	34.5	57.2	33.4	40.5	98.7	102.3	172.00	135.0	298.8	284.4	65.0	31.1
Zn	197.9	51.9	192.1	57.3	186.3	39.4	198.7	93.7	149.6	60.4	250.0	150.6	177.1	68.6
Co	25.5	15.5	18.9	5.0	19.2	4.7	34.8	20.9	24.3	20.6	37.4	18.3	15.1	5.0
Fe	6.5	1.9	5.9	1.0	6.3	1.3	6.7	1.6	11.5	6.6	14.7	5.0	6.0	1.9
Mn	2,794.5	3,756.5	1,749.0	1,385.0	2,146.3	959.9	3,176.2	3,156.8	2,514.3	3,720.1	4,376.0	4,372.1	2,228.5	1,373.7
Ca	263.2	621.5	442.5	916.6	200.7	513.6	262.3	331.4	91.8	74.5	160.0	76.5	268.7	164.3
Mg	11,770.0	7,540.9	9,181.1	3,159.1	8,009.0	2,698.3	8,531.4	2,435.6	6,450.5	2,132.8	6,504.0	3,101.0	7,057.0	3,099.3
Mo	1.0	0.9	0.8	2.7	0.8	1.2	1.3	1.0	4.2	3.0	na	na	1.3	1.8
Hg	0.1	0.1	0.2	0.1	0.2	0.1	0.0	0.0	0.2	0.0	na	na	0.0	na
U	0.6	0.3	0.5	0.2	0.9	0.6	0.8	0.5	0.7	0.5	na	na	1.4	1.5
As	17.6	12.4	10.6	9.8	14.2	18.2	31.7	22.7	42.8	46.6	na	na	25.8	32.0

Assay values in ppm except Fe in %.
m = mean
σ = standard deviation
na = no assay
n = number of samples

$$D = 0.25\,Cd + 0.53\,Cu - 0.32\,Ni + 0.31\,Pb + 0.34\,Co + 0.61\,Fe$$

A plot of discriminant scores (values for the discriminant function for each sample) demonstrates the variability and distribution of these elements in the various tills (Table 3). Lawrencetown till has a consistent distribution of scores falling within a well defined field. Few anomalous concentrations of elements are found in this till in the clay fraction. The locally derived quartzite, slate and granite tills have polymodal distributions of elements probably reflecting local bedrock mineralization, as well as influences from Lawrencetown till, as there is considerable overlap in fields. Piper and Slatt (1977) analyzed the clay mineralogy in the fine (<2m) fraction of some sandy tills and found kaolinite to be common. They concluded that the local sandy tills had a partial mixture of red clay, rich in kaolinite, which comprises a great part of the clay fraction of the Lawrencetown till.

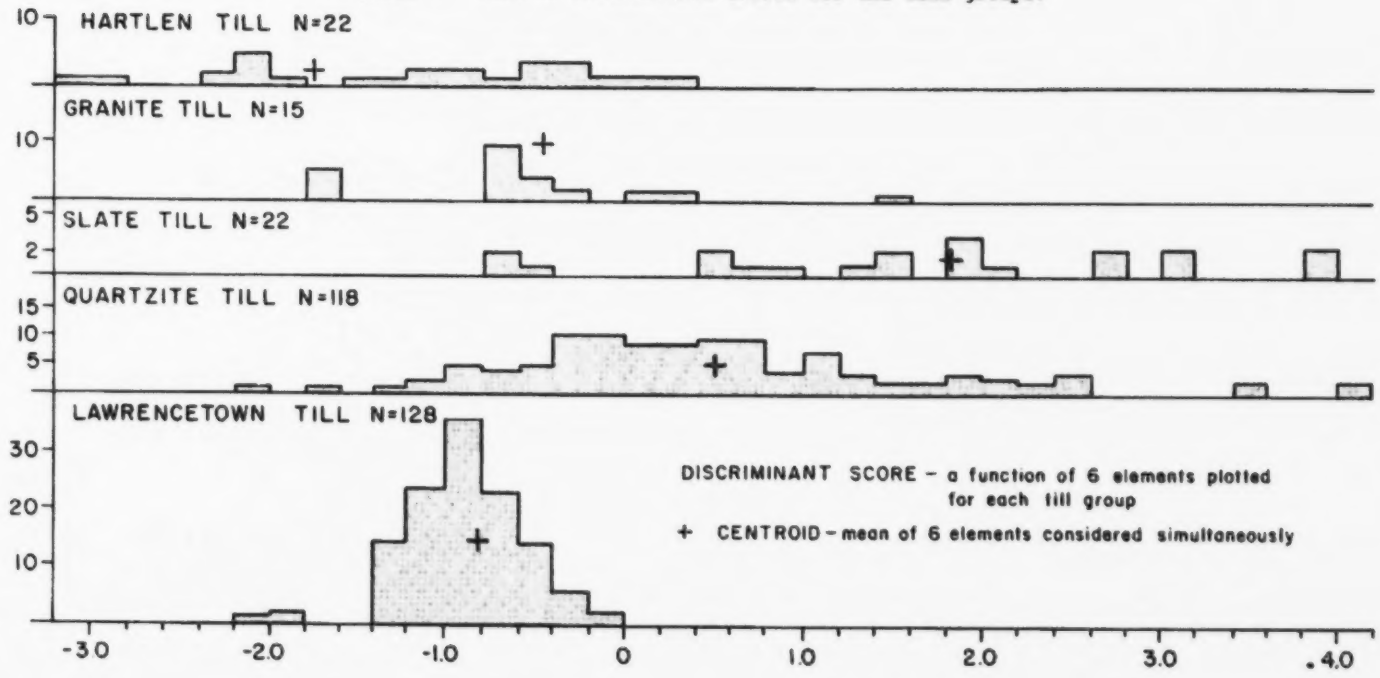
Are these tills significantly different in elemental composition? An "F" test can be done to test this hypothesis. Values for variances of these tills, considering the six discriminating elements simultaneously, can be obtained from the analyses. Two till population variances are then divided and an "F" value obtained. If this value exceeds the tabulated value obtained from a standard "F" distribution table, then the populations are considered distinct, statistically.

Comparing the two major till groups, the Lawrencetown till and the quartzite till, produces an "F" value of 1.37 which exceeds the tabulated value of 1.00 inferring them to be separate populations, statistically. A comparison of variances of the Hartlen till, granite till and Lawrencetown till produces "F" values that show no statistical difference. In Table 3, they show considerable overlap in discriminant scores. It is believed, however, that disciminant analysis considering all major till types, including sandy tills, would minimize the differences between Lawrencetown and Hartlen tills, similar in textural properties.

Correlation Matrix

A correlation matrix (Table 4) indicates a good correlation between Ni, Co and Cu (0.75). This association has also been noted in stream silts (J. Bingley, N. S. Dept. of Mines, .pers. comm.). Elevated Cu, Ni, Co and Zn values (Cu 516, Co 52, Ni 109, Zn 376 ppm) were obtained from sample 83 (see Sheet 1 in pocket) at Nickerson Lake, Guysborough County (4.5 km northwest of the town of Guysborough). The sample was taken from a sandy till at a depth of 2 m near a fault contact of volcanic rocks and Horton Group (?) conglomerates and fine grained sediments. The Cu, Ni, Co association may be indicative of mineralization in this area.

TABLE 3. Plot of discriminant scores for the till groups.



DISCRIMINANT SCORES = [.25 Cd + .53 Cu - .32 Ni + .31 Pb + .34 Co + .61 Fe]

TABLE 4. Pearson correlation coefficients.

	Ag	Cd	Cu	Ni	Pb	Zn	Co	Fe	Mn	Ca	Mg	Mo	Hg	U	As
Ag	1.0000	99.0000	.0955	.0797	.1091	.1231	.0878	.0992	.0166	.0083	.1582	.0466	99.0000	99.0000	.5353
Cd	99.0000	1.0000	.0212	.2205	.1929	.2058	.1271	.0721	.0361	.0699	.1088	.0847	.1722	.6140	.0962
Cu	.0955	.0212	1.0000	.5094	.2932	.1059	.6184	.1974	.4121	.1036	.1638	.0645	.0322	.0436	.2355
Ni	.0797	.2205	.5094	1.0000	.0275	.2381	.6288	.0725	.4851	.0224	.3153	.2512	.0760	.3077	.0646
Pb	.1091	.1929	.2932	.0275	1.0000	.1921	.3113	.5040	.2723	.0935	.1426	.5969	.2959	.0931	.2025
Zn	.1231	.2058	1059	.2381	.1921	1.0000	.1870	.0154	.1873	.0793	.1488	.1953	.1514	.0295	.0384
Co	.0878	.1271	.6184	.6288	.3113	.1870	1.0000	.1160	.5807	.0604	.1742	.0524	.0022	.1312	.1568
Fe	.0992	.0721	.1974	.0725	.5040	.0154	.1160	1.0000	.1043	.1372	.2728	.4992	.0946	.0542	.3566
Mn	.0166	.0361	.4121	.4851	.2723	.1873	.5807	.1043	1.0000	.0884	.0449	.0428	.0965	.0544	.1121
Ca	.0083	.0699	.1036	.0224	.0935	.0793	.0604	.1372	.0884	1.0000	.2227	.0014	.0732	.1727	.1209
Mg	.1582	.1088	.1638	.3153	.1426	.1488	.1742	.2728	.0449	.2227	1.0000	.1420	.0709	.1861	.0800
Mo	.0466	.0847	.0645	.2512	.5969	.1953	.0524	.4992	.0428	.0014	.1420	1.0000	.2415	.0131	.1838
Hg	99.0000	.1722	.0322	.0760	.2959	.1514	.0022	.0946	.0965	.0732	.0709	.2415	1.0000	.0106	.0142
U	99.0000	.6140	.0436	.3077	.0931	.0295	.1312	.0542	.0544	.1727	.1861	.0131	.0106	1.0000	.1038
As	.5343	.0962	.2355	.0646	.2025	.0384	.1568	.3566	.1121	.1209	.0800	.1838	.0142	.1038	1.0000

A value of 99.0000 is printed if a coefficient cannot be computed.
Significant correlations are underlined.

A weak correlation exists between Fe, Pb and Mo for all the till groups (Table 4). In tills derived from slate bedrock ("Bridgewater Conglomerate", and slate till) rich in iron (Fe > 10%) this correlation is intensified. High Pb and Mo values are found in these tills (Pb 100-600 ppm, Mo 5-30 ppm). In some of the samples enriched in Pb and Mo, anomalously low Cu, Zn, Co, Ni, and Mn values are found (eg. sample 250 - Nowlin Lake; sample 244 - Eagle Lake, see Sheet 2 in pocket) This may be an indication of weathering of sulphide deposits, where Pb is left as the residual mineral anglesite, and other metal cations are leached and removed by percolating, acidic vadose water. The porous nature of the slate till would facilitate this process. Because of the relative chemical immobility of Pb, gossans developed on sulphide ore bodies, have been found to contain relatively high Pb concentrations, and low Cu, Zn, Co, and Ni values. The Townsend Lake gossan described by Shilts (1972, p. 188) has these properties: high Pb (500-3800 ppm); low Cu (8-16 ppm),. Zn (16-35 ppm), Ni (8-11 ppm) and Co (8-16 ppm). It also is known that anomalously high Mo values can occur concentrated beyond normal background values by a process of coprecipitation with iron-manganese oxides (Horsnail and Elliott, 1971). The elevated Mo values therefore may not indicate the presence of a primary molybdenum mineral within the till sample.

SUMMARY OF MAIN CONCLUSIONS

(1) The major till units mapped in the Eastern Shore region, the Lawrencetown till and the quartzite till, can be distinguished chemically, each having significantly different Cu, Pb, Ni, Co and Cd values. If these tills, or soils developed on these tills are sampled, anomalous concentrations of elements must be defined based on the data provided for each of these till groups.

(2) The sandy facies of the drumlin Lawrencetown till is intermediate in composition between the quartzite till and the red clay facies of the Lawrencetown till, reflecting its dual local and distant provenance.

(3) The elements which contribute primarily to the discrimination of the tills are Fe, Cu, Co, Ni, Pb and Cd.

(4) Cu, Ni and Co exhibit a strong correlation. This association may represent an environment of sulphide mineralization.

(5) Pb anomalies in slate derived tills may arise from weathering of originally present sulphide grains. Low values of Cu, Zn, Co, Ni and Mn associated with the high Pb values tend to confirm this hypothesis.

(6) Weathering of labile minerals (sulphides, carbonates) in the Lawrencetown till is important to depths of 2.5 m. The porous sandy tills are believed to be weathered to depths 2-3 times greater.

TILL UNITS AS PROSPECTING TOOLS: DISCUSSION

Lawrencetown Till

This till, occurring as a ground moraine sheet on the carboniferous lowlands, can attain a thickness of >40 m. As drumlins the maximum thickness is about 25 m thick. Lawrencetown till sampled in the Musquodoboit Valley demonstrated few "kicks" compared with the relatively thin, sandy till sheet. An alternative prospecting technique on a reconnaissance scale in this till would be to obtain samples at depth and use sand-sized, heavy mineral concentrates in the analyses. To penetrate to depths of unweathered till (>3 m) a modified portable drill sampler could be used (Pionjar Hammer drill. Boniwell and Dujardin. 1964).

Lawrencetown till found in drumlins has a dual provenance, locally and distantly derived. Locally derived material is primarily tied up in the sand and pebble sized fractions. Presumably, the mixture of local and distantly derived debris in the drumlins, is due to a mixing of basal and englacial debris zones in the glacier by a basal melting process (Nielsen, 1976, 1977 p.) .When the till is red and clayey it contains very little local debris in the silt and clay fractions. The sandy facies of drumlin till in near surface samples (1-3 m) demonstrates a composition intermediate between local sandy tills and the red clay Lawrencetown till in the <2μ fraction (Table 2). Therefore sandy drumlin tills preferably should be sampled for local bedrock affinity, as they contain a greater percentage of locally derived material.

Quartzite, Slate, and Granite Tills

These tills can be used as an exploration tool for local bedrock mineralization. They are generally thin (1-4 m) and consist of <90% local clasts. Dispersion of definable (by visual classification) till facies onto adjacent rock types is in the order of 0.8-3 km.

Resistant minerals such as scheelite and cassiterite can be found in the sand-sized heavy mineral concentrates of these tills. The sand-sized mode is believed to be the terminal grade for quartz and feldspar in these sandy tills (Dreimanis and Vagners, 1969). This implies that the tills are immature, and that glacial crushing was not of a sufficient intensity and duration to break down the clasts to rock flour (silt and clay).

Labile components in these porous tills may be extensively leached in near surface samples (1-2 m) therefore use of the clay fraction (<2μ) is desirable in the exploration for sulphide ore deposits. The principle behind this is that the cations released from the labile minerals are scavenged by the <2μ fraction (clay minerals, iron-manganese oxides) in approximate proportion to the original amount of metal available in the matrix (Shilts, 1975). In quartzite till, the clay fraction is a relatively constant percentage of the matrix throughout the region.

Because of the scavenging abilities of the clay-sized fraction, it would also be possible to detect geochemical haloes around ore bodies, as the till rarely reaches depths greater than 3 m.

Hartlen Till

This till, at most exposures, is unoxidized. It is considered to be a lodgement till, primarily locally derived (1-5 km) (Grant, 1963; Nielsen, 1976). A coarse fraction may be used effectively in the till to prospect for labile and resistant minerals, which are unoxidized in the environment of this till.

ACKNOWLEDGEMENTS

The authors would like to thank D. Bernasconi and P. Belliveau who prepared the figures. S. Parsons for typing the manuscript, and Reg Morrison for the inspiring photography. This paper has been reviewed by J. M. Bingley. A. K. Chatterjee and George O'Reilly of the Nova Scotia Department of Mines and W. W. Shilts and R. N. W. DiLabio of the Geological Survey of Canada.

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